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1998

B. DATE Report Downloaded From the Internet 8/17/98

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D. Currently Applicable Classification Level: Unclassified

E. Distribution Statement A: Approved for Public Release

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Vortex Ring Generator

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Abstract

The U.S. Marine Corps Joint Nonlethal Weapons Directorate tasked the U.S. Army to demonstrate a means of quickly converting the Navy MK19-3 automatic 40-mm grenade launcher between lethal and nonlethal modes of operation. The Arm Research Laboratory (ARL) teamed with the Armament Research and Development Engineering Center (ARDEC) to demonstrate a kit for retrofitting to the weapons already stockpiled by all services. The kit enables the weapon to apply flash, concussion, vortex ring impacts, marker dyes, and malodorous pulses onto a target at frequencies approaching the resonance of human body parts. Two goals are to provide a demonstration to the U.S. Army Training and Doctrine Command in 1998 and to transition from technology base research to PM Small Arms development in 2000. This paper describes the concepts proposed for nonlethal crowd control, gaps in technology that inhibit fielding, and proposed approaches to resolution. Organizations in government, industry, or academe with common interests and active vortex ring programs are encouraged to coordinate with ARL to share resources and avoid duplication of effort.

Introduction

Vortices occur in nature as tornadoes, waterspouts, ship wakes, aircraft contrails, cannon smoke rings, nuclear clouds, etc, assuming either a spinning axial or spinning torroid shape. Because of their significant impact on the architectural, aircraft, ship, and motor vehicle industries, research into the mechanisms of formation, propagation, and stability of vortices has been published throughout the nineteenth and twentieth centuries. Serious studies of vortices and vortex motions originated by Helmholtz in his paper of 1858 [1] and continued in the work of Lord Kelvin [2], Hill [3], and others in the nineteenth century and the first half of this century. Many of the modern vortex ring studies and advances in vortex understanding are made possible because of powerful computers coupled with numerical techniques. The field of aerodynamics stimulated vortex studies related to turbulent flow, stabilities, and instabilities, and a description of the status of vortex dynamics is given by P. G. Saffman [4]. Other work [5–7] describes vortex stability research performed in the 1970s by the current Secretary of the Air Force, the Honorable Dr. S. E. Widnall. Additional studies on steady and turbulent vortex rings are given by Fraenkel [8] and Maxworthy [9]. A bibliography of Soviet research from 1975 to 1987 is provided by Akhmetov et al [10]. Stanaway et al [11] conducted a viscous vortex ring numerical study using a spectral method to characterize this type of gas flow. Other Army studies [12–14] looked into the delivery of agents such as tear gas using vortex rings, and Navy research [15,16] aimed at generating vortex rings with gas combustion and focusing on down-range targets.

No literature was found showing successful fielding of any weapon system based on vortex research. In 1996, Dr. Andrew Wortman of ISTAR, Inc., proposed to construct a nonlethal weapon—namely, a vortex ring generator—for crowd control. The goals were to knock down a human target using repeated impacts by vortex rings and to apply dispersal agents such as tear gas. The proposal differed from the published literature in that propane and gasoline were to initiate vortex rings rather than military explosives. Figure 1 is an artist's image of a low-cost, man-portable system.

This concept was not pursued by ARL, largely because it required fielding of an entirely new system, and the trend in the Army was to reduce weight and logistics costs. ARL instead elected to develop a kit that could be retrofitted to an existing weapon system and thereby enhance performance by enabling quick conversions between lethal and nonlethal modes of crowd control.

ARL proposed a kit for the MK19-3 automatic 40-mm grenade launcher, and the U.S. Army Armament Research Development and Engineering

Center (ARDEC) initiated a program in May 1997 under the sponsorship of the U.S. Marine Corps Joint Nonlethal Weapons Directorate. The goals are to conduct a proof-of-principle demonstration for the Training and Doctrine Command in FY98 and to transition the program from ARL technology base research to PM Small Arms engineering development in FY00.

This paper outlines the technology gaps as perceived by the authors and proposes approaches for resolution. The program is not sufficiently mature to document the results of studies. The objectives of the paper are to outline the proposed program so that other organizations in government, industry, and academe that have active programs may consider coordinating with ARL to leverage resources and avoid duplication of effort.

Technical Background

Two situations of crowd control were considered at the onset of the vortex ring generator program. One was a small group of people positioned at knife-throwing distances, such as in a civilian prison riot, and the suggestion was that the 40-mm MM1 revolver grenade launcher, shown in figure 2, could be modified for nonlethal operations in these close quarters. The other situation considered was a large rioting crowd, threatening troops at a stone-throwing distance. The vision here was that a mobile, truck-mounted MK19-3 automatic 40-mm grenade launcher, shown in figure 3, could be modified for nonlethal crowd control in open areas. Only the large crowd situation is addressed here, but the technology is easily extended to the small group situation.

The concepts presented here are based on first-hand experiences with large riots in the Middle East, which left a sense of "thermoclines" in the crowd; i.e., the first few rows of people were "hot" and dangerous, and the back rows were "cooler" adventurers, who only become dangerous if mishandled. In the past, the entire crowd would be attacked with tear gas, clubs, dogs, or horses, and the result was often a larger crowd recongregating somewhere else. The modern approach uses stand-off techniques such as rubber bullets applied to individual leaders, but this is not always nonlethal and tends to incite the rioters. This paper examines the concept of crowd control using a vortex ring generator that is designed to target individuals, persuade them to

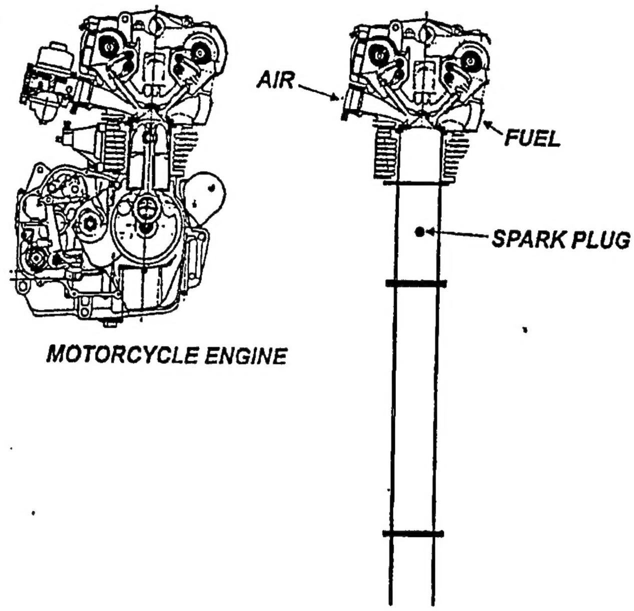

Figure 1. Conceptual variable-speed vortex ring generator.

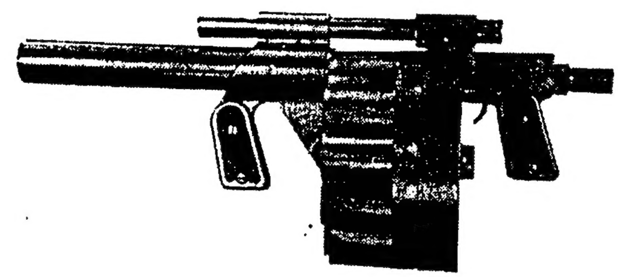

Figure 2. 40-mm MM1 revolver grenade launcher.

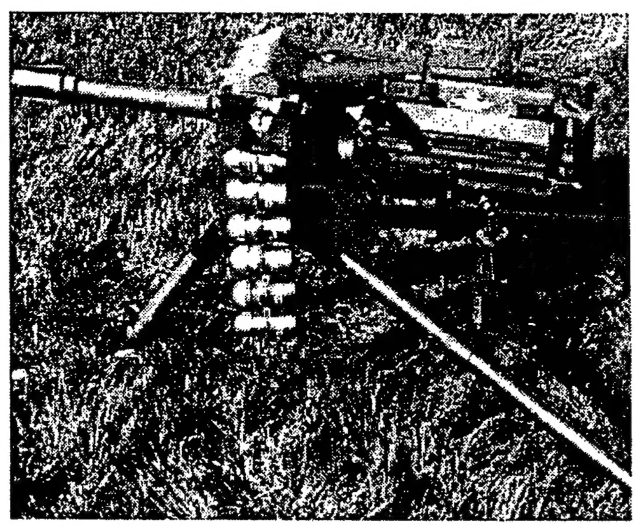

Figure 3. 40-mm MK19-3 automatic grenade launcher.

vacate the area, and promote a divorce from the main body without reprisals on the gun crew.

The vortex ring generator is a recently proposed concept for integrating several nonlethal technologies into a single weapon system. One design goal is to apply to the targeted individual a series of flash, impact, and concussion pulses at frequencies near the resonance of human body parts. Another design goal is to apply malodorous agents and marker dyes. The reasoning is that application of a malodor such as cortyl mercapton (skunk perfume) to a specific individual will cause the crowd to voluntarily pull away from that individual. And, if an individual is subjected to a chain of impulses that cause physiological discomfort, the individual will vacate the area. The net result is a break in leadership and communication without reprisals (few people have been known to return for revenge on a skunk).

ARL intends to extend the capabilities of the standard issue MK19-3 automatic 40-mm grenade launcher by designing a kit that can be retrofitted to the weapon and thereby enable quick conversions between lethal and nonlethal modes of operation. The kit consists of two components, a link of blank cartridges and a cylindrical rod. The rod houses a supersonic nozzle and reservoirs for marker and malodorous materials. The rod is mounted by sliding down the barrel until affixed to the flash arrestor. No special tooling is required, and one can quickly return the launcher to a lethal mode by pulling the rod out by hand and loading a link of live ammunition. The rod is designed to prevent accidental firing of lethal ammunition and is to be discarded after use.

Component Design Consideration

Figure 4 is an artist's view of the blank cartridge, nozzle, and barrel assembly. The blank cartridge is being developed at ARDEC, and ongoing patent processing inhibits disclosures at this time. Basic design requirements are proper chambering during automatic fire, seamless interfacing at the nozzle, and obstructed chambering of a live round to preclude accidental lethal firings. The principle of operation is for automatic firing of blank cartridges to generate high-pressure pulses of gas that are expanded by the nozzle to atmospheric pressure and to high mach number jet streams, whereupon a string of agent-laden vortex rings propagates down range, as shown in figure 5.

The nozzle must be designed to drastically reduce or eliminate the standing shock, turbulence, and burning that occurs in the conventional muzzle blast shown in figure 6. The detrimental effect of the standing shock (mach disk) on vortex propagation is apparent in figure 7, where a well-formed vortex ring unable to jump the standing shock wave is being consumed by the muzzle blast.

The ideal muzzle blast for forming and propagating a vortex ring is a short-duration "fire-hose" type of jet stream with a small expansion angle, as shown in figure 8. ARL researchers captured the image in figure 9, which shows a low-energy, 40-mm vortex ring formed in these conditions. The postulated mechanisms are that boundary layer spill-over from the nozzle causes the core to form, spin-induced entrainment of ambient air causes the core to grow, and muzzle blast convection helps the core to propagate. In this method of formation, the core of a vortex does not have to be located in space in order to inject an agent; agents are simply injected into the nozzle boundary layer. The disadvantage is inefficiency: only a fraction of the jet stream energy is transferred to the vortex and, consequently, range and effectiveness at the target are not optimal.

ARL is conducting an analytical/semi-empirical research program aimed at identifying the parameters critical to optimization of the vortex ring and to derive

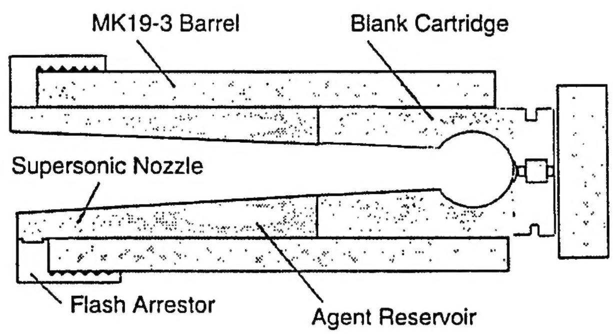

Figure 4. Artist's view of rod and cartridge assembled into gun barrel.

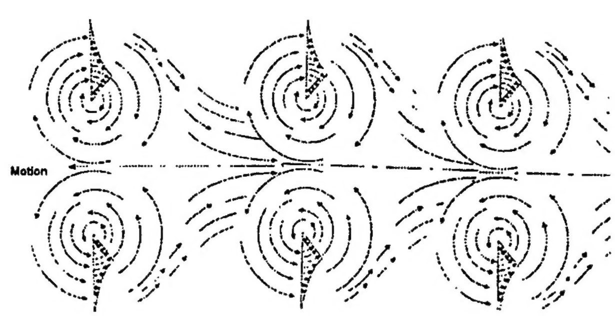

Figure 5. Series of agent-laden vortex rings propagated by automatic fire.

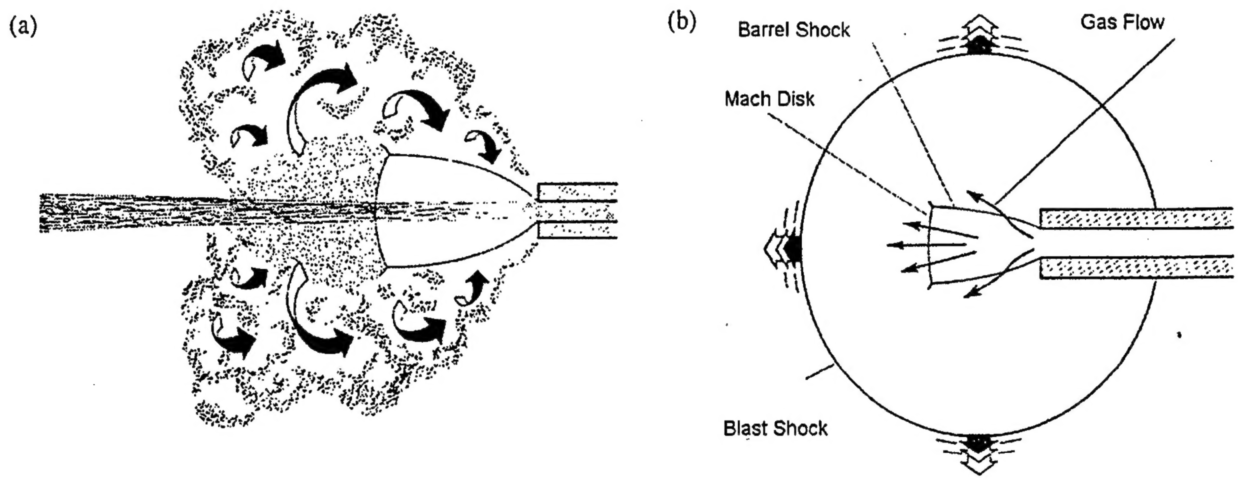

Figure 6. Illustration of muzzle blast showing (a) turbulence, burning, and shocks; and (b) traveling blast shock wave and stationary mach disk.

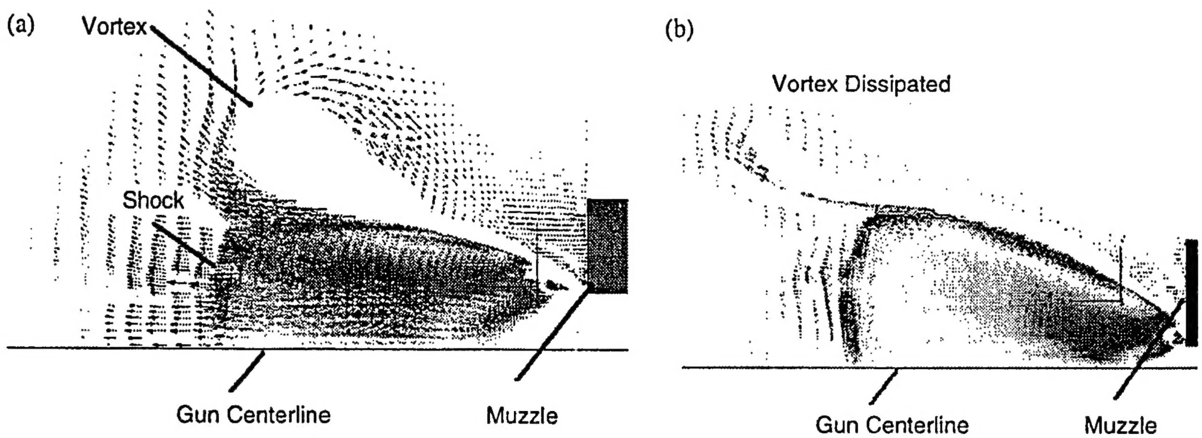

Figure 7. Half view of vortex ring: (a) expanding over normal shock (courtesy of M. Slaby, Adaptive Res., Inc.) and (b) ring consumed by the muzzle blast.

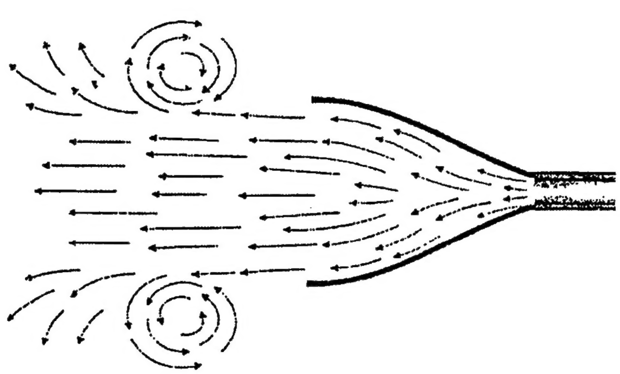

Figure 8. Laval nozzle eliminates standing shock wave (mach disk) and associated turbulence by expanding gas to atmospheric pressure.

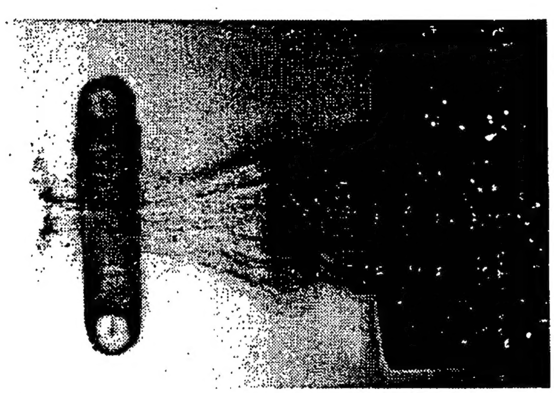

Figure 9. Low-energy, 40-mm vortex image captured by spark photography. (Courtesy of Dr. D. Lyon (ARL) and F. Dindl (ARDEC).)

scientifically based design tools for transition to development engineers at ARDEC. Computer modeling is being performed using the Adaptive Research Computational Fluid Dynamics (CFD) 2000 program and a dual-Pentium Pro personal computer. ARL plans to work in cooperation with Johns Hopkins University and to use this program in part to examine an alternate mechanism for forming a vortex—namely, to roll up the entire muzzle blast. The principle is to design the cartridge and nozzle such that the length of the gas pulse emitted from the nozzle nearly equals the diameter. The postulation is that the "spherical" shape will transform into a torroid in the fashion of the fireball in a nuclear blast. One significant advantage of this mechanism of formation is that larger quantities of agents may be transported to the target area using fewer rounds of ammunition. A possible disadvantage may be reduced range due the higher initial drag as the vortex is forming.

Regardless of the mechanism of vortex formation, the two major concerns about vortex transportation of agents are spillage and target effectiveness. Agents may spill at the gun site; in flight, agents may miss the target and strike wrong targets due to cross wind dispersal; and, agents may fail to reach the target due to wind gust shattering. We propose to resist dispersion and shattering by maximizing the angular and linear kinetic energies of the vortex using supersonic nozzles. To minimize gun site contamination, we intend to inject binary materials that must mix in flight to activate, and, to mitigate in-flight spillage from centrifugal forces, we propose to transport gaseous agents rather than aerosols.

The effectiveness of a vortex when arriving at human target is an issue for the nonlethal medical community, and guidance is needed regarding the physiological effects that may be expected from combined, low-frequency (3–15 Hz) flash, concussion, vortex, and malodorous pulses. This information is critical to the design and operation of the system. To illustrate, consider the MK19-3 in automatic fire, generating a chain of vortex rings, as shown in figure 5. The vortices will tend to leap frog and self-destruct if target effectiveness mandates vortex rings with large diameters and small separations.

Gunfire tests of nozzles and cartridges provided by ARDEC and EWS, Ltd., will be conducted at ARL, in the enclosed test chamber shown in figure 10. This facility was designed by ARL and EWS, Ltd., largely to protect the environment and staff from the acoustics and agents generated in live-fire experiments.

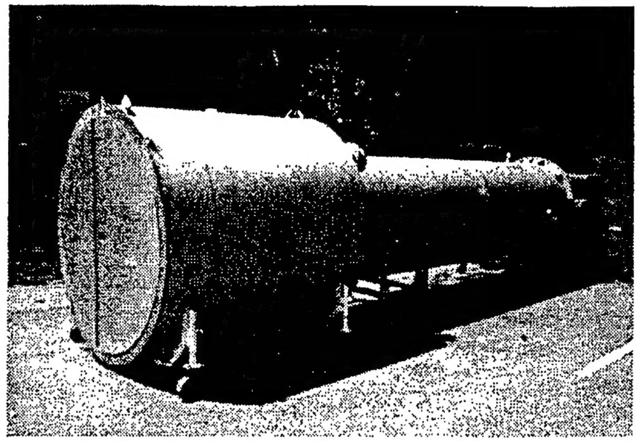

Figure 10. Confined firing chamber for vortices containing agents.

Summary

Vortex research is well documented in the published literature, but none of the studies appear to have led to fielding of a weapon system. ARL proposes to advance the state of the art by focusing on supersonic nozzles for vortex ring propagation. A fundamental technology gap is the absence of scientific design guidelines for the unsteady, nonisotropic, nonadiabatic flow that occurs when firing a blank into a nozzle. Other gaps are the absence of design guidelines for optimizing the kinetic energy and agent-carrying capacity of a vortex, transporting maximum quantities of agents, resisting dispersion and shattering in flight, and medical effects of resonating human body parts. Semi-empirical testing is required and modeling will be used to develop design tools for transition to ARDEC when a proof-of-principle demonstration of the vortex ring generator is completed. Currently, the technology gaps have been defined and approaches to resolution have been identified. A cooperative agreement has been established with ARDEC for cartridge research. An enclosed facility has been constructed for performing environmentally friendly, live-fire testing of agents. Computing hardware and software have been purchased, and prototype nozzles and cartridges are being fabricated.

Instrumentation for detecting the linear and angular kinetic energies of a vortex while still located in the muzzle blast remain undefined, and coordination of medical effects studies remain to be organized. Researchers having common interests and seeking to coordinate studies, facilities, and resources are requested to contact George Lucey by e-mail at glucey@arl.mil, by telephone at (301) 394-4342, or by fax at (301) 394-2677.

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